Aleksandra Kostecka*

LOWER MUSCHELKALK CARBONATES OF THE SOUTH-WESTERN MARGIN OF THE HOLY CROSS MOUNTAINS (CENTRAL POLAND)

PART II. DIAGENESIS

(Pl. I—IV)

Utwory węglanowe dolnego wapienia muszlowego południowo-zachodniego obrzeżenia Gór Świętokrzyskich

Cz. II. Diageneza

(Pl. I—IV)

A b s t r a c t: The work deals with diagenetic evolution of the Lower Muschelkalk sediments. The following problems are considered: submarine versus vadose early cementation, mineral composition of an early cement (non-ferroan palisade calcite cement of the first generation), chemical composition of the Muschelkalk marine waters, evolution of primary mud into microspar (syntaxial cementation), generation of microspar-size cement in the mud-supported deposits, development of blocky calcite cement (the second generation) and its composition and neomorphism simultaneous with the late cementation.

INTRODUCTION

In the second part of the paper related to the Lower Muschelkalk carbonates of the south-western margin of the Holy Cross Mts., the orthochemical components of carbonate rocks and diagenetic processes are discussed.

Electron micrographs were made in the laboratories of the Electron Microscopy of the Institute of Metallurgy of the Polish Academy

---

* Academy of Mining and Metallurgy. Institute of Geology and Mineral Resources, al. Mickiewicza 30, 30-059 Kraków.

of Science and of the Scanning Microscopy of the Jagiellonian University. The author expresses her sincere gratefulness to the Menagement and to the Staff of these institutions.

ORTHOCHEMICAL COMPONENTS OF CARBONATE ROCKS

There exist, in the investigated rocks, both orthochemical components built of calcite i.e. micrite, microspar, sparry cement (spar) and pseudospar (neomorphic calcite), and noncarbonate autigenic minerals i.e. gypsum, chalcedone (lutecite), quartz and feldspars. The noncarbonate minerals have not been examined in detail.

The orthochemical components are minerals precipitated in a sedimentary or diagenetic environment, they bear no traces of transport. Among them only the carbonate mud (micrite or microspar in a lithified sediment) could have been displaced before the final deposition.

Folk (1959, 1962) introduced the term „micrite" to determine the diagenetic counterpart of the primary carbonate mud, chemically or biochemically precipitated in a sedimentary environment. The mud, when settling on the bottom, may suffer some later drifting by weak currents. As a conventional size maximum for the micrite grains the cited author accepted 4 µm.

Gradually, the term „micrite" started to be used for comparatively small cement crystals (cf. Alexandersson, 1969, 1972, Ginsburg et al., 1971, Schroeder 1972, 1973, 1974 and others) and lost its quasi-genetic aspect. It became purely descriptive and as such has been used in this paper.

The term „spar" corresponds to the cement precipitated on the free surfaces of grains or in intragranular voids. The size of its crystals is dependent, among others, on the available void space. The term „spar" is essentially of genetic meaning, especially since the term „pseudospar" (Folk, 1965) has been introduced for recrystallized calcites.

As most of the investigators of the Middle Triassic carbonates agree (Skupin, 1970, 1973, Bachman, 1973, Schwarz, 1975), in the investigated limestone micrite occurs rarely. The matrix of most of the limestones is composed of microspar (Pl. I, Fig. 1), the diagenetic equivalent of the original carbonate mud.

The sparry cement appears mainly in biosparites and pelsparites i.e. in limestones built of dense packed grains. It also occurs in smaller amounts in other kinds of limestones, coating grains and filling voids.

In the above meaning „spar" corresponds to cement, but the latter is essentially a broader term, for it may be developed as crystals of micrite or of microspar size.

Pseudospar (Pl. III, Figs. 3, 4, 5) prevails in organic remains recrystallized in situ. Recrystallization (neomorphism) of other components is not very common.

Microspar and micrite

Recent deposits of shallow marine environments are mainly composed of aragonite or aragonite-calcite muds. They originate as a result of:
— Dying of calcareous algae, especially of green algae. They produce in their thallus aragonite needles which accumulate, after decay of the organic matter, as a loose sediment (Lowenstam, 1955, Stockman et al., 1967);
— Breakdown and abrasion of aragonite and calcite remains (cf. Matthews, 1966);
— Physico-chemical and biochemical precipitation of calcium carbonate out of supersaturated marine water (Cloud, 1962, Wells and Illing, 1964, Neev and Emery, 1967).

The last mentioned process is the most controversial one. Precipitation of aragonite has been ascertained in the supersaline conditions of the Dead Sea (Neev and Emery, 1967). This problem remains unsettled when concerning the Great Bahama Bank muds. According to Cloud (1962) they could also result from physico-chemical processes.

The origin of muds in the Muschelkalk sea may be only the matter of speculation. Because of poverty in the calcareous algae, the first of the processes discussed above appears the least probable. Bachman (1973) disagrees with the conception of the origin of mud as a result of disintegration and abrasion of organic remains, because of a low grade of rounding of skeletons. However, the conception mentioned above should not be disregarded. The organic remains, especially the pelecypod and gastropod shells tend to break up into microstructural elements of mud size (cf. Force, 1969). It is not possible to recognize such elements if they originate from break up of skeletons with fibrous or thinly prismatic microstructure. The results of break up can be relatively easily distinguished in case of shells with thick prismatic structure, because of a considerable size of individual prisms (about 0,15 mm). There are lot of such particles in the Lima striata Beds (cf. Part I, Pl. V, Fig. 4). Neither the single prisms nor fragments composed of a few of them indicate any rounding, whereas the micritized skeletal fragments with their original structure destroyed, are subjected to it. According to the author, break up and abrasion of skeletal remains were an important source of carbonate muds.

The third of the cited sources — the physico-chemical (and biochemical) precipitation of mud out of the supersaturated marine water can

2*

not be denied, yet till now it has been too little investigated to be properly evaluated.

The recent carbonate muds are built of aragonite and high magnesian calcite that change to low-magnesian calcite during diagenesis: Mg--calcite loses Mg ions as a result of an incongruent dissolution (Berner, 1967, Land, 1967) but aragonite is replaced by calcite *in situ* (Schlanger, 1964) or dissolved and again precipitated as calcite. Those changes occur in the diagenetic environment with pore water devoid of Mg ions.

It is not known whether the composition of the Lower Muschelkalk muds was similar to the recent ones. However, since the neomorphism is only slightly marked in the microsparite limestones, it appears that these muds were built mainly of stable minerals (calcite).

According to Folk (1965) the primary carbonate muds converted into micrite during diagenesis, can be consequently changed into microspar, i.e. the more advanced stage of neomorphism. The neomorphic genesis of microspar can be supported (Folk, op. cit.) by following arguments:

— Microspar often occurs as patches in unaltered micrite, being in no relation to the bedding;

— Microspar often starts as fringes around allochems, forming an aureole of neomorphism. A radial arrangement of crystals around the allochems excludes a detrital origin of microspar;

— Microspar is often associated with terrigenous clay minerals, considered to be a hydraulic equivalent of a calcareous sediment composed of clay-sized particles.

However, it appears that microspar of the investigated limestones never existed as micrite. This conception can be supported by following observations:

— Microspar often displays a horizontal, parallel and lenticular lamination and cross-lamination (cf. Part I, Pl. III, Fig. 2). These features point to a transport and segregation of material;

— Microspar growing druse-like on the allochems shows all the features of cement (Pl. I, Figs. 1, 2, Pl. II, Fig. 1) and differs from the cement of biosparite by size only (Pl. IV, Fig. 1). In this case no neomorphic aureole can thus be taken into account;

— Microspar of the matrix lacks features characteristic for the neomorphic calcite (cf. Pl. I, Fig. 1 and Pl. III, Figs. 3, 4);

— No micrite patches have been found in microspar;

— In favour of existence of various grain sizes in the original carbonate mud are microsparites (of Permian age) horizontally laminated and simultaneously graded bedded, that indicates a possibility of microspar origin as a result of a mechanical segregation of mud (Pl. III, Fig. 1).

Being aware of the importance of the neomorphic processes the author presumes, however, that neomorphism is not the only way to-

wards generation of microspar. For example, microspar can be a diagenetic equivalent of a silt fraction appearing in the original mud (Bathurst, 1959). Moreover, it can also result from a syntaxial cementation of the primary mud particles growing due to dissolution of the unstable particles.

In the investigated rocks of the Lower Muschelkalk no micritic limestones have been found.

Basing on all those data it has been accepted that the carbonate mud originating from different sources had been subjected to a mechanical transport and sorting, likewise the clastic material. After deposition, in the mud soaked with marine water and presenting the same porosity as the recent muds (cf. Ginsburg, 1957, Pray, 1960, Pray and Choquette, 1966), processes of an early diagenesis begun i.e. a gradual dehydratization, dissolution of unstable particles and precipitation of cement. A submarine cementation of carbonate muds is accepted by Choquette (1968) basing on data from isotopic analyses of oxide and carbon.

The cement crystallized in an optical continuity with crystallites of organic structures and with mud particles (cf. Bathurst, 1959), changing the latter into microspar. This process caused a gradual hardening of the sediment and elimination of pores. It is possible that the characteristic elongation of many microspar grains has been caused by a faster growth of cement in direction of the optic axes of the primary particles.

The syntaxial cementation proceeded in the thin layer of the sediment near the surface, under oxidazing conditions. The source of cement was marine water supersaturated in respect to $CaCO_3$, and unstable aragonite particles dissoluted during the early diagenesis. Thus originated microspar is represented by grains slightly bigger than the primary mud particles.

In the limestone of Middle Triassic, micrite is of little importance. It appears only as micrite envelopes and crusts and chamber fillings of some gastropods (cf. Part I). Some peloids are built of micrite too.

Two types of micrite envelopes have been distinguished (cf. Part I). The envelopes of the type I are formed as a result of a replacement of an original particle by micrite filling vacated microborings (Bathurst 1964, 1966). Micritization is centripetal and gradually eliminates the primary substance. In some skeletal remains single, small patches of micrite, corresponding to particular borings, can be noticed (Pl. II, Fig. 4). The carbonate cement precipitating in borings is of micrite size, because of small void dimensions. This cement probably results from both the physico-chemical (Alexandersson, 1972) and the biochemical processes connected either with metabolism of algae or with the bacterial disintegration of the organic matter (Kendall and Skipwith, 1969, Lloyd, 1971, Margolis and Rex, 1971, Alexandersson, 1974).

The envelopes of the type I are of variable thickness. Micritization

is often limited to the external parts of the attacked allochems, however, in extreme case, it can eliminate the primary material and turn the grain into a peloid (cf. Part I).

Within the micrite envelopes formed on the calcite skeletons, primary microstructure is partly or wholly preserved, due to a relatively high stability of the organic calcite.

The micrite envelopes developed on the aragonite remains surround calcite casts after dissolved aragonite (Pl. II, Fig. 2). It can be assumed that, after dissolution of the aragonite and before precipitation of the calcite cement, the micrite envelope surrounded the void. If at this stage compaction took place, the micrite envelope was breaking, forming collapse structure (cf. Part I, this volume fasc. 2)

Presence of collapse structures in the microsparite matrix indicates the degree of consolidation of the sediment during compaction (Čatalov, 1971). The fragments of micrite envelopes wholly buried in the sediment indicate dissolution of the organic aragonite and compaction taking place before consolidation of mud. Broken micrite envelopes, covered with cement of the first generation with exception of fracture surfaces, indicate both dissolution of the organic aragonite before the early cementation and compaction after crystallization of the first generation cement (cf. Part I).

Micritization indicates conditions favouring colonization of grains by microborers. These conditions are: a low mobility of colonized grains and a sufficient light penetration. The latter is however, of no significance in case of the heterotrophic microborers (Friedman et al., 1971).

The envelopes of the type II (Davies and Kinsey, 1973) are formed either as a result of a mechanical trapping of mud particles in the sticky organic film coating the calcareous grains or as a result of a biochemical precipitation of micrite within it. Under pressure the envelopes behave like those of the type I.

The recent micrite envelopes are built of aragonite and high Mg-calcite (Bathurst, 1966, Winland, 1968, Purdy, 1968, Alexandersson, 1972), but their fossil counterparts are built of low Mg-calcite.

If to admit that in the marine environment of the Muschelkalk the aragonite skeletons were coated with aragonite micrite envelopes, then, since dissolution of the aragonite skeletons in these rocks is known, a question arises why aragonite of the organic remains became dissolved when the same mineral of the micrite envelopes was transformed into calcite without any visible structural change. Is it possible for the same mineral to behave differently under identical diagenetic conditions? Such question cannot be answered unequivocally. However, the author supposes that the envelopes were built not of aragonite as in the recent environments but of calcite with eventually a slight addition of

$MgCO_3$. A small amount of Mg^{+2} ions in the calcite micrite would explain the high resistance of the micrite envelopes to dissolution.

Beside the micrite envelopes there appears sometimes a structureless micrite in form of swellings and knobby crusts on the skeleton or peloid surfaces (cf. Part I, Pl. II, Fig. 2). According to Čatalov (1972) the crusts present biosedimentary structures of microstromatolite type. Nevertheless, it is possible that micritization of encrusting foraminifers takes place here.

Cement

In the Lower Muschelkalk limestones cement is built of calcite growing free on the grain surfaces and filling up the voids. It is often quite difficult to distinguish the calcite cement from the neomorphic (recrystallized) calcite. Here, the criteria presented by Bathurst (1971, p. 417) can be helpful.

By the method of staining with alizarine red S and potassium ferricyanide solution (see Friedman, 1959, Evamy 1963, Dickson, 1965, Hutchison, 1974) the following varieties of cement have been detected:
— orange-pink non-ferroan calcite cement;
— pink — pale violet cement with small amount of Fe^{+2};
— violet ferroan calcite cement:
— blue, strongly ferroan calcite cement [1]

Orange-pink non-ferroan calcite cement

Development of non-ferroan calcite cement depends on the type of the substratum, size of voids and time of crystallization.

In biosparites, biopelsparites and pelsparites cement develops on the grain surfaces as layer composed of thin, long, steep-faced crystals relatively tightly arranged (Pl. IV, Figs. 1, 5). This kind of cement was called palisade cement (Schroeder, 1972). Inside the skeletal grains, mainly in voids left after the dissolved aragonite shells, the cement crust is usually very thin and sometimes even absent. In the first case dissolution of skeletal aragonite begun with some delay in relation to the cement precipitation but ended early enough for cement to crystallize in voids, forming a layer thinner than on the grain surfaces, sometimes a layer of tiny initial crystals only. In the second case (lack of cement crust) dissolution of skeletal aragonite has taken place after crystallization of the non-ferroan calcite cement (cf. Bachman, 1973). The steep-faced cement crystals are generally not observed on the compaction fracture surfaces. Hence, it appears that cement crystallization was prior to compaction and to the collapse structure as well (cf. Bathurst, 1964).

---

[1] In the following text the colour of calcite cement means the colour obtained by staining.

The palisade cement forms crusts of stable thickness (Pl. IV, Fig. 5) around the grains in the biosparite. However, if in the proximity cement develops in an optical continuity with the echinoderm plates, growth of the palisade cement will be stopped (Pl. III, fig. 6) by the syntaxial cement growing faster (cf. Lucia, 1962). Many examples of cement in an optical continuity with echinoderm „monocrystals”, with radial crystals of foraminifer tests (Pl. IV, Fig. 3), with thin prisms of ostracod carapaces and prisms of pelecypod shells were noted.

The tiny voids left in biomicrosparites mainly after the thin-shelled fauna, are filled with non-ferroan cement built of more or less izometric crystals of microspar size (20 to 30 μm). This type of cement has been called granular cement.

On the whole, the thinnest, slender and steep-faced crystals of the orange-pink cement were found in the Lima striata Beds (Pl. IV, Figs. 1, 5). In lower units, especially in the Wolica Beds, cement developed as rather short and thick crystals. It is possible that this difference was caused by different quantities of Mg ions in the calcite lattice (cf. Folk, 1973, 1974).

Many examples of microspar-size cement were found on the surfaces of the skeletal grains embedded in the microsparite matrix (Pl. I, Figs. 1, 2, Pl. II, Fig. 1). Those grains were buried in the calcareous mud where they remained in no contact with one another. It has been generally assumed that the mud enveloping the grains impedes the growth of cement. However, the author considers the growth of cement possible, especially if crystallites of organic structures are of an appropriate crystallographic shape and optical orientation, and the sediment — of an adequate porosity. As stated by Neugebauer (1974), in chalk type sediment mainly syntaxial growth of cement with crystallites of some organic structures (e. g. echinoderm plates, inoceram prisms) has been observed. This process is influenced by the crystal size and the crystal shape of the particles. The growth of cement in optical continuity with such particles is faster than development of cement on grains, which size, shape and optical orientation are not appropriated. So, it can be assumed that presence of microspar-size cement results from its faster crystallization on the skeletal grains than on mud particles also subjected to cementation.

It is remarkable that both the skeletal remains and microspar of the matrix as well as micrite of the micrite envelopes acquire the same orange-pink colour as the discussed non-ferroan cement. So, it means, that all the processes of micritization, mud cementation leading to formation of microspar, and crystallization of cement occurred under oxidazing conditions.

In the microsparite matrix a phenomenon can be observed that confirms the hypothesis of the syntaxial cementation of mud particles.

Some of the microspar grains are characterized by presence of orange-pink nuclei on which develops the violet calcite in an optical continuity. The contact between the differently coloured zones is sharp. These grains are grouped in small patches scattered in the microsparite matrix of an uniform orange-pink colour.

The process of syntaxial cementation is, most probably, very common, but it is very difficult to be found because of small crystal size and possible changes of the oxidation-reduction potential in the diagenetic environment. Under oxidizing conditions the non-ferroan calcite cement crystallizing on the non-ferroan mud particles forms crystals lacking zonal structures.

Ferroan calcite cement

Other types of cement: the violet-pink, violet and blue (after staining) have been called blocky cements (cf. Dunham, 1969, Schroeder, 1972) because of large, izometric crystals which are not, at least apparently, in any relation to the substratum (Pl. II, Fig. 3, Pl. IV, Figs. 1, 5). In the very small voids there sometimes appears the violet granular cement of the same size and shape as the orange-pink one.

The intercrystalline boundaries in the mosaic of blocky cement are often built of plane interfaces and among triple junctions with the palisade cement, enfacial junctions are not uncommon (cf. Bathurst, 1964, 1971). That proves a gap between crystallization of the palisade cement and the blocky one.

The coloured variants of the blocky cement often form zonal crystals. There was found an optical continuity between the ferroan calcite cement, non-ferroan calcite cement and bioclastic nuclei (Pl. IV, Fig. 4).

The sequence of crystallization of cement around the bioclastic monocrystals (echinoderm plates) is as follows:
— the orange-pink, non-ferroan calcite cement grows syntaxially, immediately on the surface of the echinoderm plate;
— on it, also in an optical continuity, develops a zone of the violet or violet-pink cement with a thin subzone next to the non-ferroan cement; usually, the subzone is of an intensive violet colour, it is in a sharp contact to the non-ferroan calcite cement and, being parallel to the latter, passes gradually outwards into the violet-pink calcite cement (Pl. IV, Fig. 4);
— the last to crystallize in an optical continuity is the blue calcite cement. It fills the remaining pore spaces between the grains.

Each zone of the ferroan calcite cement can contain thin, differently coloured subzones. Their boundaries are usually not sharp in contrast with the clearly marked external boundary of the non-ferroan calcite cement.

Generations of cement

The above described sequence of the cement crystallization: non-fer-
roan calcite — sharp boundary — ferroan cement, is the same for all
monocrystals with bioclastic nuclei. A similar sequence occurs in voids:
the non-ferroan palisade cement crystallizes directly on the grain surfa-
ces and the internal part of pore spaces is filled with the ferroan blocky
cement (Pl. II, Fig. 3, Pl. IV. Figs. 1, 5).

Taking into account colour, shape and position in relation to the
substratum, the non-ferroan orange-pink calcite cement has been consi-
dered as the first generation, and the ferroan blocky cement — as the
second generation (cf. Oldershow, 1971).

Between the crystallization stages of the first and the second gene-
ration cement a time break took place, easily noticed in case of the
sequence: palisade cement — blocky cement. The layer of the steep-fa-
ced (palisade) cement is characterized by a dog-tooth surface separating
both generations (Pl. IV, Fig. 1) between which no genetic relation has
been observed. Discontinuity of crystallization is also stressed by pre-
sence of the compaction fracture surfaces not lined with the palisade
cement but covered directly by crystals of the blocky cement (cf. Ba-
thurst, 1964). This discontinuity is not seen in case of monocrystals with
bioclastic nuclei where the zonal structure is visible only after applica-
tion of staining.

The simple and clear scheme of the sequence of cement crystalliza-
tion is slightly disturbed by the ferroan granular cement. It cannot be
distinguished from the non-ferroan granular cement and even from the
microsparite matrix without application of staining. This cement appears
rarely: Its relation to the blocky cement is not clear. It is possible that
granular ferroan cement represents the first generation developed un-
der conditions of the negative oxidation-reduction potential. However,
there is another possibility: the ferroan granular cement is the one of
the second generation, of size limited by void dimensions.

According to the research in recent (reef) sedimentary-diagenetic en-
vironments, there appear in a relatively short interval of time several
cement generations which do not result from macro-changes of environ-
mental agents. The repeating processes of sedimentation and cementa-
tion run almost simultaneously, and cement (aragonite and Mg-calcite)
is characterized by a variable fabric (cf. Ginsburg et al., 1971, Schroe-
der, 1972, 1973 and others). So, separation of the only two cement ge-
nerations in the Lower Muschelkalk limestones is a considerable simpli-
fication. However, as a generation, all the cement crystallizing under
stable in the macro-scale diagenetic conditions should be taken into
account and, it is possible, that as a result of subtle changes of the en-
vironment, subgenerations could have been generated. Nevertheless,

a picture of such cement subgenerations in rather monotonous micro-sparites and biomicrosparites is much less clear than in reefs with their primary an secondary voids in which all generations of internal sediments and the cementation stages can be registered (cf. Zankl, 1971, Schmidt, 1971, Ginsburg and Schroeder, 1973, Schroeder and Zankl, 1974). Attemps to distinguish such subgenerations were succesful for definite beds only. But, as up till now, no general correlation has been reached. Probably, one could attain much better results by applying cathodoluminescence (cf. Meyers, 1974).

Discussion

The first generation cement has been considered as an early diagenetic product of calcium carbonate crystallization in marine environment, and the second generation cement — as an effect of crystallization under relatively deep subsurface conditions.

An early submarine cementation is supported by the following:

— Lack or only slight traces of compaction in microsparites and biomicrosparites (coprolites are not compacted);

— Presence of intraclasts being at the moment of erosion, in various stages of consolidation, completely lithified included (cf. Zankl, 1969);

— Presence of rock-borers, serpulids and oyster-like pelecypods, connected with the existence of hardgrounds.

During crystallization of the first generation cement the diagenetic marine environment was under oxidazing conditions. Another possibility — reducing conditions and lack of Fe^{2+} ions is less possible, although the final effect in form of non-ferroan calcite cement would be the same. Evamy's suggestions (1969) that the non-ferroan calcite cement was being formed above the ground water table under subaerial condition (i. e. in vadose zone) are not motivated in case of the Lower Muschelkalk deposits. Neither the meniscus (Dunham, 1971) nor the gravitational (Müller, 1971) nor the stalactite cement (Purser, 1969, 1971) which are considered as cementation criteria for the vadose zone have been found. There is, as well, no vadose internal sediment in voids (cf. Dunham, 1969). Sediment covering the first generation cement appears only in case of infiltration of the material from the overlying bed, bringing one more evidence of the considerable speed of cementation.

It is possible, that under generally oxidizing conditions of the early diagenetic environment the negative oxidation-reduction potential and consequently, crystallization of the ferroan granular calcite cement could have occurred. The cause of such changes could be found in a local accumulation of the decaying organic matter or in a strong supply of clay hampering the exchange of the marine water with the one penetrating through the sediment.

The source of the first generation cement was calcium carbonate originating partly from the dissolved skeletal aragonite remains and partly from marine waters saturated with respect to $CaCO_3$.

In pace with growing thickness of deposits, the solutions penetrating partly cemented sediments, were gradually losing contact with marine water, what, most probably, brought about the end of the first (early diagenetic) phase of cementation.

The ferroan blocky calcite cement of the second generation was developping in a different diagenetic environment. Its crystallization was slow, possibly with time breaks, resulting in large, often izometric calcite crystals. Because of reducing conditions, some Ca ions in the calcite lattice were substituted by Fe^{2+} ions. The variable amount of Fe^{2+} ions, causing a characteristic scale of colours in calcite crystals, probably reflects the changes in the chemical composition of pore solutions (cf. Evamy, 1969).

It is difficult to establish when the second phase of cementation of carbonate sediments began. Nevertheless, it did not immediately follow the early cementation stage. It is indicated not only by the compaction (collapse) structures, but also by the pressure-solution which results, among others, in microstylolites. In the pressure-solution processes participated the grains, the matrix and the first generation cement but not the second generation one.

At the end of the Late Triassic the Lower Muschelkalk deposits were not deeply buried. The rocks of the Middle and the Upper Muschelkalk are not of big thickness (some tens of metres) and the Keuper sediments were in a great part removed in result of pre-Rhaetian uplift and following erosion (Senkowiczowa, 1970). So, one can assume that the diagenetic processes were somehow influenced by meteoric waters deeply penetrating and mixing with relic pore solutions of marine origin. The meteoric waters, poor in Mg ions brought about the final elimination of aragonite remains, preserved till then. Crystallization of the blocky calcite began from the solutions enriched with calcium carbonate. Cementation took place probably in the phreatic zone where the reducing conditions and considerable mobility of water could be expected. According to Land (1970), cementation in the phreatic zone is much faster than in the vadose zone, although, there are different opinions on this subject (cf. Benson, 1974).

As a source of the second generation cement, the dissolution of the organic aragonite and pressure-solution, should be considered, especially in relation to the marly sediments. Whether these sources provided an amount of $CaCO_3$ adequate for cementation — it is not known. Stylolitization could be considered as a potential source of cement, but some of stylolites are younger than the blocky calcite cement.

Mineral composition of the cement of the first and the second generations

The second generation cement was developing under conditions of burial and inflow of meteoric waters usually poor in Mg ions. There is no doubt that it was built of the most stable form of $CaCO_3$ i. e. the low Mg-calcite.

The question of the first generation cement now also built of low Mg-calcite, is more complicated. As an early diagenetic component crystallizing under submarine conditions it should be, from the actualistic point of view, aragonite or Mg-calcite. Had it be aragonite primarily, it would have to be subjected, in the late diagenetic environment of pore solutions poor in Mg ions, to neomorphic changes or, like the organic remains, dissolved. According to Schneidermann et al. (1972), Sandberg et al. (1973) and Sandberg (1975a, b) in the neomorphic calcite some relics of the primary aragonite structure of organic and inorganic origin (for example cement) are preserved. However, in the calcite crystals of the first generation cement neither aragonite relics (Pl. IV, Fig. 1) nor features typical of neomorphic calcite have been found. This cement is definitely a product of direct crystallization from solutions.

It is possible that the cement of the first generation now present in the rocks, replaced the earlier aragonite cement completely dissolved under conditions of fresh water inflow. In such a case, it should be accepted that these processes took place in the vadose zone where the positive oxidation-reduction potential, necessary for the crystallization of the non-ferroan calcite cement, could be expected, and where the fresh waters would make the low Mg-calcite development possible. Arguments againts the vadose zone as the environment of the diagenetic changes are as follcws:

— Lack of internal sediments in the primary and secondary voids (cf. Dunham, 1969);

— Lack of relation between the neomorphosed skeletal grains (see p. 313 and the first generation cement;

— Lack of meniscus (Dunham, 1971), gravitational (Müller, 1971) and microstalactite cements (Purser, 1969, 1971);

— Presence of early diagenetic gypsum in beds now situated in the saturation zone (bore-hole Piekoszów IG-1); this mineral was removed from rocks being now in the vadose zone and remaining voids were filled with silica of lutecite type (cf. Folk and Pittman, 1971, Siedlecka, 1972).

Because of the lack of proofs for the vadose cementation, together with the arguments stated above (p. 307) in favour of the submarine cementation, the author assumes that the first generation calcite cement was a low Mg-calcite, eventually, with a slight addition of $MgCO_3$.

Two stages of cementation were distinguish: the synsedimentary

submarine cementation (cement of the first generation) and the late diagenetic cementation under shallow burial (cement of the second generation). The diagenetic processes (among others stylolitization, and crystallization of cement in the tectonic fractures) probably continued under relatively deep burial caused by sedimentation of Jurassic and Cretaceous deposits.

The crystallization of calcite cement in the Muschelkalk sea would have been possible if Mg/Ca ratio in the marine water was lower than 2 : 1 (recently 5 : 1). A possibility of such conditions in the ancient seas is suggested by Sandberg (1975b). According to this author the abundant development of planktonic foraminifers and coccolithophorids building the skeletons of low Mg-calcite, could have highly influenced the increase of Mg/Ca ratio through binding and removing Ca ions from the oceanic system (cf. Li et al., 1969).

The highest part of the Lima striata Beds was deposited under different conditions than the lower units so one can assume that its synsedimentary cementation run in different way. A gradual increase in salinity, indicated by appearance of an early diagenetic gypsum, and extinction of fauna at junction of the Lower and Middle Muschelkalk, could have influenced both the diagenetic environment and the kind of the crystallizing cement. Thus, one should consider that both the primary aragonite and the Mg-calcite cements could have existed in those deposits, especially, since some signs of neomorphism of the first generation cement have been indicated (see p. 313, 314). So, dissolution of aragonite shells before deposition of the immediately higher sediment requires some explanation (cf. Part I, p. 219). The author suggests that some parts of the marine bottom could have emerged, locally and for a short time only. It is possible, that those parts were either situated in the tidal zone or even in supratidal one from time to time flooded by waves, so that the marine water was penetrating into deposits. Salt concentration was growing up due to evaporation, thus resulting in precipitation of gypsum. Subsequently, in periods of intensive rainfalls, the aragonite skeletons close to the sediment surface were being dissolved.

NEOMORPHISM

In 1965 Folk suggested "a comprehensive term of ignorance" i. e. neomorphism, to describe the transformations between one mineral and itself or a polymorph. Neomorphism includes inversion (or a polymorphic transformation) and recrystallization but does not concern replacement of a mineral by any other one of a different chemical composition.

In this paper the term "neomorphism" concerns only the aggrading neomorphism (Folk, 1965). The author could not find any example of

the degrading neomorphism i. e. diminution of grains as a result of re-crystallization (cf. Orme and Brown, 1963, Wolf, 1965). Formation of micrite envelopes i. e. micritization, is not connected with recrystalliza-tion but with crystallization of cement in borings.

In the Lower Muschelkalk deposits the neomorphic transformations are easy to trace within organic structures.

In respect to the grade of neomorphism the organic remains have been divided as follows:

— Elements of primary microstructure preserved; under the light micro-scope no transformations were found in them;

— Elements in which stages of the neomorphic transformations may be observed;

— Neomorphosed elements with weak relics of primary structure.

The first group is represented by skeletal remains of echinoderms, brachiopods, nodosarids, serpulids, ostracods and by some calcite layers of pelecypod shells (e. g. Lima striata). These skeletons or their parts were probably built, like the recent forms, of low and high Mg-calcite. In case of skeletons built of Mg-calcite the loss of Mg ions and trans-formation into the low Mg-calcite was being accomplished without any changes in their microstructure, that could be observed under the light microscope (cf. Friedman, 1964). However, there can be some ultrastruc-tural changes visible under the electron microscope only (cf. Sandberg, 1975a). They were observed in ostracod valves. Under the light micro-scope the microstructure of an ostracod valve makes an impression of an unchanged homogenous-prismatic one, what is furthermore, empha-sized by the syntaxial cement. However, on a SEM photomicrograph, a clearly developed cement can be observed but the prismatic structure is at least problematic (Pl. II, Fig. 3).

The second group contains the elements in somehow „fixed" stages of neomorphic transformations. Here predominate pelecypod shells or more exactly, the calcite layers of their shells, usually accompanied by cement casts of the primary aragonite layers.

Neomorphism is performed as follows:

— In the primary microstructure composed of crystallites generally in-distinguishable under the light microscope, some single neomorphic crystals appear (Pl. III, Fig. 2), which are of irregular shapes and with tendency to imitate the primary framework;

— Growth of the neomorphic crystals causes their extention beyond the shell layer where the neomorphism begun; relics of layered struc-ture as dark ghost lines transect neomorphic sparry mosaic (Pl. III, Figs. 2, 3, 4);

— In the final stage, a mosaic of irregular neomorphic crystals, elon-gated normal to the layer surface is formed, and ghost lines disap-pear in places (Pl. III, Figs. 3, 4).

A typical feature of the neomorphic calcite crystals is an undulose or semi-composite light extinction and usually orientation of optic axes normal to the direction of crystal elongation. This phenomenon was observed by Lindholm (1974), in respect to calcite crystals considered by the mentioned author, as neomorphic.

To the third group there belong the skeletons of pelecypods and gastropods, built of neomorphic calcite only, without any traces of the primary structure, apart from the ghost lines. These remains are in the final stage of neomorphism.

A characteristic feature of the organic remains of all three groups is their pale-brown colour and pseudo-pleochroism (cf. Hudson, 1962). Together with increasing intensity of neomorphism the brown colour grows paler.

To a separate group belong skeletons (mainly pelecypod remains) built of a single calcite crystal with undulose extinction, in which some brown inclusions appear oriented according to a scheme conditioned, most probably, by the primary microstructure. These inclusions can be oriented: parallely to layer surface of a shell, perpendicularly and obliquely to it; the optical axes are oriented in the same way. The light extinction is wavy, as, for example, in the calcite shell layer of *Lima striata*. However, in the latter case, the homogenous-prismatic microstructure of the layer is visible — in the skeletons mentioned above, no details of the primary structure can be distinguished. Taking into consideration the orientation of inclusions and of optic axes, the primary structure of particular skeleton can be approximately reconstructed: a parallel orientation of optic axes and lines of inclusions indicates a fibrous structure with the orientation of crystallites parallel to a layer surface, whereas the normal orientation indicates a prismatic structure with crystallites perpendicular to the layer surface. An oblique orientation indicates a prismatic structure with crystallites inclined to the layer surface.

Although, in the microstructure of the elements mentioned above some transformations took place, which obliterated the individual features of particular crystallites, the author is not sure, mainly because of lack of reorientation of the optic axes, whether the neomorphism can be taken into account. Most probably, obliteration of crystallites was caused by the loss of organic matter. A similar phenomenon was observed in foraminifers of radial structure though in their ultrastructure no transformations were found (Pl. IV, Fig. 3).

Subsequently, a question arises: at what stage of diagenesis did the neomorphic transformations take place? The following observations help to dissolve this problem:

— The first generation cement grows in an optical continuity with the

elements of preserved primary structure but it does not form crystals syntaxial with neomorphic calcite;

— The second generation cement grows in an optical continuity with crystals of neomorphic calcite. If a skeleton is surrounded by the two cement generations, the calcite of the second generation is in an optical continuity with neomorphic calcite of organic structure but the first generation calcite cement preserves its individuality (Pl. III, Fig. 3, 4);

— In case of an optical continuity between the second generation cement and neomorphic calcite the optic and crystallographic axes are oriented normally to the layer surface. Inside the shell, where no contact between neomorphic calcite and cement exists, the optic axes of the neomorphic calcite are mostly perpendicular to the elongation (crystallographic axes) of crystals (cf. Lindholm, 1974).

Basing on the above given data, one can assume that neomorphism was simultaneous with development of the second generation cement (cf. Benson, 1974). The neomorphic transformations were, most probably, influenced by pore solutions from which cement was precipitated. It is difficult to established whether orientation of neomorphic calcite was forced by cement crystallizing syntaxial with it or, to some extend, by the primary microstructure. The author considers the first possibility as more probable, at least in the zone of junction of cement with the neomorphosed organic structure. As indicated by Schroeder (1973), skeletons may be replaced by neomorphic calcite which is in an optical continuity with the blocky, low Mg-calcite, though the aragonite cement of an older generation occurring between the blocky cement and neomorphic calcite, is not affected by the transformations.

The primary mineral composition of the neomorphosed skeletal remains will be discussed next.

Aragonite cannot be considered as mineral building up skeletons of the second group because the still preserved primary microstructure gives a negative result when treated with Feigl's solution (Pl. III, Fig. 2). The fact of different neomorphic stages being „fixed" in a skeleton may be eventually explained by different amount of Mg ions in crystallites and related different response to neomorphic transformations.

The skeletons of the third group could be built of Mg-calcite as well as aragonite. However, they are often accompanied by cement casts, what points at an early dissolution of aragonite layers. Thus, in such cases, it is more probable that the neomorphosed layers had been primarily built of Mg-calcite.

In the higher part of the Lima striata Beds, examples have been found, indicating neomorphism of the first generation cement. In fact an optical continuity was found between both generations of cement

and the neomorphic calcite of skeletal remains. The remains and the first generation cement are orange-pink coloured, whereas the second generation cement, growing syntaxially with the former, is blue. Change of colour between these two generations is not sharp. In this case the sequence of the diagenetic events has been as follows:

— Crystallization of the first generation cement (aragonite and/or Mg--calcite) on skeletal grains;

— Crystallization of the late diagenetic cement (the second generation) from pore solutions with simultaneous neomorphism of both metastable cement of the first generation and of the organic remains.

Moreover, within the blocky cement, some small pores were found, (Pl. IV, Fig. 2), which may indicate an early presence of the primary aragonite cement (cf. Schneidermann et al., 1972, Sandberg et al., 1973). The question of neomorphic changes in the Muschelkalk deposits requires still more investigations.

Essentially, the neomorphic events are limited to the examples here discussed. In some deposits, recrystallization within coprolites (the Lima striata Beds) can be found, sometimes also in other peloids. Though, such examples are more rare than it should be expected.

CONCLUSIONS

Diagenesis includes changes occurring in a sediment under conditions of a relatively low temperature and pressure, and leading to transformation of loose sediments into hard rock. Choquette and Pray (1970) distinguished three stages of diagenesis: eo-, meso- and telogenetic. Eogenesis includes a time interval beginning with the final deposition and ending with burial of sediments. The mesogenetic stage includes the period of a more or less deep burial of sediments, where the operating processes are not immediately influenced by surface agents. The telogenetic stage is connected with rock uplift, erosion and weathering. In comparison to other authors (cf. Strachow, 1953, 1960, Fairbridge, 1967, Chilingar et al., 1967), Choquette and Pray (op. cit.) enlarged the notion of diagenesis by incorporating into it the weathering processes reaching down to the ground water level. The author adopts the terminology of the cited authors but excludes the telogenetic stage from diagenesis.

In relation to the Lower Muschelkalk deposits, during eogenetic stage the following processes were operating: partial dissolution of organic aragonite, bioturbations, an early cementation (cement of the first generation), a gradual dehydration of a sediment accompanied by a slight compaction and, in places, crystallization of gypsum.

In the mesogenetic stage, there took place: processes of compaction

and pressure-solution, further dissolution of still existing aragonite ske-
letons, a late diagenetic cementation (cement of the second generation)
accompanied by neomorphism of metastable minerals, and stylolitiza-
tion. Migration of silica should be also taken into account in this
stage.

The telogenetic stage is connected with karts processes, dissolution
of gypsum and precipitation of silica in place of the latter. Those pro-
cesses were not investigated in detail.

The diagenetic processes, and conditions under which they opera-
ted in the Lower Muschelkalk deposits, were as follows:

1. Before the final deposition of some sediments, there occurred micri-
tization of skeletal grains and, locally, intra- and intergranular cemen-
tation of many particles of manifold origin, lying on the sea bottom in
contact with one another, from which grapestones and other peloids
generated. Subsequently, those grains were redeposited, partly at least,
and formed cross laminated or horizontal laminated sediments.

2. The main phase of the early diagenesis (the eogenetic stage) begun
with the final deposition of the sediment. Diagenesis was considerably
conditioned by the type of the sediment and rate of its deposition (cf.
Shinn, 1969). In calcareous muds, a gradual dehydratization and decre-
ase in porosity took place (cf. Ginsburg, 1957). Probably, dehydratiza-
tion was of little importance in more coarse-grained sediments devoid
of mud.

In areas of slow sedimentation, the early cementation was probably
almost simultaneous with deposition. To deposits of such type belong
mainly microsparites and some biomicrosparites, where postdepositio-
nal trace fossils as well as coprolites are found. The lack of Fe^{2+} ions
in calcite lattice indicates that the early diagenetic cement (the first
generation) was being formed in an oxidizing environment. The trace
fossils are also proofs of the oxidizing conditions.

Presence of intraclasts, lithified coprolites and rock-borers, as well
as slight compaction in microsparites, indicate a fast cementation in
the submarine environment. The source of the cement was marine wa-
ter supersaturated with $CaCO_3$ and the dissolved organic aragonite.

A mineral precipitated as cement of the first generation was cal-
cite, probably containing a low percent of $MgCO_3$. However, taking
into consideration the change of crystal habit (cf. Folk, 1973, 1974) in
the Muschelkalk profile, it can be assumed that in the upper parts of
the Lower Muschelkalk sequence, the chemical composition of calcite
cement was being gradually changed, the amount of Mg ions was gro-
wing due to an increase in salinity and evaporation.

No proofs of precipitation of aragonite cement nor of neomorphism
of the first generation cement (with exception of the cement in the
upper part of the Lima striata Beds) and, evidences of dissolution of

3*

aragonite skeletons, suggest that in the Early Muschelkalk sea the Mg/Ca ratio was different than in the recent oceans. Quite probably, this ratio was lower than 2:1; so, there was a possibility of nucleation of inorganic calcite (cf. Folk, 1974, Sandberg, 1975b) as cement (activity of bacteria and algae could be important). Precipitation of aragonite cement could have occurred in the higher part of the Lima striata Beds, because of an increase in salinity and crystallization of $CaCO_3$ and gypsum; thus a gradual elimination of Ca ions from solution and a rising Mg/Ca ratio took place.

The calcite cement of the first generation is a cement growing syntaxially with crystallites of organic structures, and probably, with the calcareous mud particles. It seems, that increase of grain size of primary carbonate mud up to microspar size, also results from this process.

Growth of the palisade cement of microspar size was observed on skeletal remains buried in mud. Because the crystals are small they can be distinguished from the microsparite matrix only by applying of an electron microscope.

3. The mesogenetic stage begun when thickness of the overlying sediment increased and the marine water supply was cut off. Compaction resulting from accumulation of the overlying beds caused collapse structures in partly cemented but still porous sediment. Thus, the compaction fracture surfaces lack cement of the first generation, what allows to consider the compaction as early mesogenetic.

During Keuper and Rhaetian, in connection with sea regression and uplift, meteoric water deeply penetrating and mixing with relics of marine pore fluids, had probably a considerable influence on diagenesis. From those poor in Mg ions solutions dissolving the still preserved aragonite skeletons, the blocky cement of the second generation crystallized. Simultaneously, meteoric waters enabled recrystallization (neomorphism) of grains built of metastable carbonates.

The late diagenetic cementation (second generation) was taking place under reducing conditions, what is indicated by presence of Fe^{2+} ions in the lattice of the blocky calcite.

The main source of cement of the second generation is not known. Some amounts of $CaCO_3$ could have been supplied by both the pressure-solution and dissolution of organic aragonite.

4. The telogenetic stage started at the moment of uplift of rocks to the subsurface zone. The main processes were: karst formation, dissolution of gypsum and migration of silica as well as its precipitation

REFERENCES — WYKAZ LITERATURY

Alexandersson T., 1969. Recent littoral and sublittoral high-Mg calcite lithification in the Mediterranean. Sedimentology, 12: 47—61.

Alexandersson T., 1972. Micritization of carbonate particles: processes of precipitation and dissolution in modern shallow-marine sediments. Bull. Geol. Insts. Univ., Uppsala, N. S., 3: 201—236.

Alexandersson T., 1974. Carbonate cementation in coralline algal nodules in the Skagerak, North Sea: biochemical precipitation in undersaturated waters. J. Sediment. Petrol., 44: 7—26.

Bachman G-H., 1973. Die karbonatischen Bestandteile des Oberen Muschelkalkes (Mittlere Trias) in Südwest-Deutschland und ihre Diagenese. Arb. Inst. Geol. Paläont. Univ. Stuttgart, N. F. 68: 1—99.

Bathurst R. G. C., 1959. Diagenesis in Mississippian calcilutites and pseudobreccias. J. Sediment. Petrol., 29: 365—376.

Bathurst R. G. C., 1964. The replacement of aragonite by calcite in the molluscan shell wall. IN: J. Imbrie and N. D. Newell (Eds). Approaches to Paleoecology. Wiley, New York, p. 357—376.

Bathurst R. G. C., 1966. Boring algae, micrite envelopes and lithification of molluscan biosparites. Geol. J., 5: 15—32.

Bathurst R. G. C., 1971. Carbonate sediments and their diagenesis. Developments in sedimentology, 12, Elsevier, 620 pp.

Benson L. V., 1974. Transformation of polyphase sedimentary assemblage into a single phase rock. J. Sediment. Petrol., 44: 123—135.

Berner R. A., 1967. Comparative dissolution characteristics of carbonate minerals in the presence and absence of aqueous magnesium ion. Am. J. Sci., 265: 45—70.

Chilingar G. V., Bissel H. J., Wolf K. H., 1967. Diagenesis in carbonate rocks. Developments in sedimentology, 8: 179—322. Elsevier, Amsterdam.

Choquette P. W., 1968. Marine diagenesis of shallow marine lime-mud sediments: insights from O^{18} and C^{13} data. Science, 161: 1130—1132.

Choquette P. W., Pray L. C., 1970. Geological nomenclature and classification of porosity in sedimentary carbonates. Am. Assoc. Petrol. Geol. Bull., 54: 207—250.

Cloud Jr. P. E., 1962. Environment of calcium carbonate deposition west of Andros Island, Bahamas. U. S. Geol. Surv., Profess. Papers, 350: 1—138.

Čatalov G., 1971. Certain diagenetic processes in the progress of lithification of the Triassic limy sediments in the Teteven Anticlinorium. Geol. Inst. Bull. Ser. Stratigraphy and Lithology, 20: 157—176. Bulgarian Acad. Sci. (in bulg. english summary).

Čatalov G. A. — Чаталов Г. А., 1972. Микростроматолиты в некоторых триассовых известняках и нх генетическое значение. C. R. Acad. Bulg. Sci., 25: 369—372.

Davies P. J., Kinsey D. W., 1973. Organic and inorganic factors in Recent beach rock formation, Heron Island, Great Barrier Reef. J. Sediment. Petrol. 43: 59—81.

Dickson J. A. D., 1965. A modified staining technique for carbonates in thin section. Nature, 205: 587.

Dunham R. J., 1969. Early vadose silt in Townsend mound (reef), New Mexico. IN: G. M. Friedman (ed.), Depositional environments in carbonate rocks: a Symposium — Soc. Econ. Mineral. Paleont. Spec. Publ., 14: 139—181.

Dunham R. J., 1971. Meniscus cement. IN: O. P. Bricker (ed.), Carbonate cements. Studies in Geology, 19: 297—300. Johns Hopkins Press, London, Baltimore.

E v a m y B. D., 1963. The application of a chemical staining technique to a study of dedolomitization. *Sedimentology*, 2: 164—170.

E v a m y B. D., 1969. The precipitational environment and correlation of some calcite cements deduced from artificial staining. *J. Sediment. Petrol.*, 39: 787—793.

F a i r b r i d g e R. W., 1967. Phases of diagenesis and authigenesis. IN: G. Larsen and G. V. Chilingar (Eds.), Diagenesis in sediments. *Developments in sedimentology*, 8: 19—89. Elsevier, Amsterdam.

F o l k R. L., 1959. Practical petrographic classification of limestones. *Am. Assoc. Petrol. Geol. Bull.*, 43: 1—38.

F o l k R. L., 1962. Spectral subdivision of limestone types. IN: W. E. Ham (ed), Classification of carbonate rocks. *Am. Assoc. Petrol. Geol.*, Mem. 1: 62—84.

F o l k R. L., 1965. Some aspects of recrystallization in ancient limestone. IN: L.C. Pray and R. C. Murray (eds.), Dolomitization and limestone diagenesis: a Symposium — *Soc. Econ. Paleont. Mineral Spec. Publ.*, 13: 14—18.

F o l k R. L., 1973. Carbonate petrography in the Post-Sorbian age. IN: R. N. Ginsburg (ed.), *Evolving concepts in sedimentology*. The Johns Hopkins University Press, Baltimore and London, p. 118—158.

F o l k R. L., 1974. The natural history of crystalline calcium carbonate: effect of magnesium content and salinity. *J. Sedim. Petrol.*, 44: 40—53.

F o l k R. L., P i t t m a n J. S., 1971. Length-slow chalcedony: a new testament for vanished evaporites. *J. Sediment. Petrol.*, 41: 1045—1058.

F o r c e L. M., 1969. Calcium carbonate size distribution on the west Florida shelf and experimental studies on the microarchitectural control of skeletal breakdown. *J. Sediment. Petrol.*, 39: 902—934.

F r i e d m a n G. M., 1959. Identification of carbonate minerals by staining methods. *J. Sediment. Petrol.*, 29: 87—97.

F r i e d m a n G. M., 1964. Early diagenesis and lithification in carbonate sediments. *J. Sediment. Petrol.*, 34: 777—813.

F r i e d m a n G. M., G e b e l e i n C. D., S a n d e r s J. E., 1971. Micritic envelopes of carbonate grains are not exclusively of photosynthetic algal origin. *Sedimentology*, 16: 89—96.

G i n s b u r g R. N., 1957. Early diagenesis and lithification of shallow water carbonate sediments in south Florida. IN: R. J. LeBlanc and J. G. Breeding (eds.), Regional aspects of carbonate deposition — *Soc. Econ. Paleont. Mineral.*, Spec. Publ., 5: 80—99.

G i n s b u r g R. N., M a r s z a ł e k D. S., S c h n e i d e r m a n n N., 1971. Ultrastructure of carbonate cements in Holocene algal reef of Bermuda. *J. Sediment. Petrol.*, 41: 472—482.

G i n s b u r g R. N., S c h r o e d e r J. H., 1973. Growth and submarine fossilization of algal cup reef, Bermuda. *Sedimentology*, 20: 575—614.

H u d s o n J. D., 1962. Pseudo-pleochroic calcite in recrystallized shell limestones. *Geol. Mag.*, 99: 492—500.

H u t c h i s o n C. S., 1974. Laboratory handbook of petrographic techniques Carbonates. Wiley. London. p. 24—30.

K e n d a l l C. G. S. C., S k i p w i t h P. A. D'. E., 1969. Holocene shallow water carbonate and evaporite sediments of Khor al Bazam, Trucial Coast, southwest Persian Gulf. *Am. Assoc. Petrol. Geol. Bull.*, 53: 841—869.

L a n d L. S., 1967. Diagenesis of skeletal carbonates. *J. Sediment. Petrol.*, 37: 914—930.

L a n d L. S., 1970. Phreatic versus vadose meteoric diagenesis of limestones: evidence from a fossil water table. *Sedimentology*, 14: 175—185.

L i Y—H., T a k a h a s h i T., B r o e c k e r W. S., 1969. Degree of saturation of $CaCO_3$ in the oceans. *J. Geophys. Res.* 74: 5507—5525.

L i n d h o l m R. C., 1974. Fabric and chemistry of pore filling calcite in septarian veins: models for limestone cementation. *J. Sediment. Petrol.*, 44: 428—440.

L l o y d R. M., 1971. Some observations on Recent sediment alteration („micritization") and the possible role of algae in submarine cementation. IN: O. P. Bricker (ed.), *Carbonate cements.* Johns Hopkins University Press, Baltimore, p. 72—79.

L o w e n s t a m H. A., 1955. Aragonite needles secreted by algae and some sedimentary implication. *J. Sediment. Petrol.*, 25: 270—272.

L u c i a F. J., 1962. Diagenesis of a crinoidal sediment. *J. Sediment. Petrology*, 32: 848—865.

M a r g o l i s S., R e x R. W., 1971. Endolithic algae and micrite envelope formation in Bahamian oolites as revealed by scanning electron microscopy. *Geol. Soc. Am. Bull.*, 82: 843—852.

M a t t h e w s R. K., 1966. Genesis of Recent lime mud in southern British Honduras. *J. Sediment. Petrol.*, 36: 428—454.

M e y e r s W. J., 1974. Carbonate cement stratigraphy of the Lake Valley Formation (Mississippian), Sacramento Mountains, New Mexico. *J. Sediment. Petrol.*, 44: 837—861.

M ü l l e r G., 1971. „Gravitational" cement: an indicator for the vadose zone or the subaerial diagenetic environment. IN: O. P. Bricker (ed.), *Carbonate cements,* Johns Hopkins University Press, Baltimore, p. 301—302.

N e e v D., E m e r y K. O., 1967. The Dead Sea. Depositional processes and environments of evaporites. *Israel Geol. Surv. Bull.*, 41: 1—147.

N e u g e b a u e r J., 1974. Some aspects of cementation in chalk. IN: K. J. Hsü and H. C. Jenkyns (eds.), Pelagic sediments: on land and under the sea. *Inter. Assoc. Sedim., Spec. Publ.*, 1: 149—176.

O l d e r s h a w A. E., 1971. The significance of ferroan and non-ferroan calcite cements in the Halkin and Wenlock limestone (Great Britain). IN: O. P. Bricker (ed.), *Carbonate cements.* Johns Hopkins Press, Baltimore, p. 225—229.

O r m e G. R., B r o w n W. W. M., 1963. Diagenetic fabric in the Avonian limestones of Derbyshire and North Wales. *Proc. Yorkshire Geol. Soc.*, 34: 51—66.

P r a y L. C., 1960. Compaction in calcilutites. *Geol. Soc. Am. Bull.*, 71: 1946 (abstract).

P r a y L. C., C h o q u e t t e P. W., 1966. Genesis of carbonate reservoir facies *Am. Assoc. Petrol. Geol. Bull.*, 50: 632 (abstract).

P u r d y E. G., 1968. Carbonate diagenesis: an environmental survey. *Geol. Romana*, 7: 183—228.

P u r s e r B. H., 1969. Syn-sedimentary marine lithification of Middle Jurassic limestones in the Paris Basin. *Sedimentology*, 12: 205—230.

P u r s e r B. H., 1971. Middle Jurassic synsedimentary marine cements from the Paris Basin, France. IN: O. P. Bricker (ed.), Carbonate cements. Johns Hopkins Press, Baltimore, p. 178—184.

S a n d b e r g P. A., 1975a. Bryozoan diagenesis: bearing on the nature of the original skeleton of rugose corals. *J. Paleont.*, 49: 587—606.

S a n d b e r g P. A., 1975b. New interpretations of Great Salt Lake ooids and of ancient non-skeletal carbonate mineralogy. *Sedimentology*, 22: 497—537.

S a n d b e r g P. A., S c h n e i d e r m a n n N., W u n d e r S. J., 1973. Aragonitic ultrastructural relics in calcite-replaced Pleistocene skeletons. *Nature Phys. Sci.* 245, no. 148: 133—134.

Schlanger S. O., 1964. Petrology of limestones of Guam. *U. S. Geol. Surv. Profess. Papers*, 403—D: 1—52.

Schmidt V., 1971. Early carbonate cementation in Middle Devonian bioherms, Rainbow Lake, Alberta. IN: O. P. Bricker (ed.), *Carbonate cements*. Johns Hopkins Press, Baltimore, p. 209—220.

Schneidermann N., Sandberg P. A., Wunder S. J., 1972. Recognition of early cementation of aragonitic skeletal carbonates. *Nature Phys. Sci.*, 240: 88—89.

Schroeder J. H., 1972. Fabrics and sequences of submarine carbonate cements in Holocene Bermuda cup reefs. *Geol. Rundschau*, 61: 708—730.

Schroeder J. H., 1973. Submarine and vadose cements in Pleistocene Bermuda reef rock. *Sediment. Geology*, 10: 179—204.

Schroeder J. H., 1974. Carbonate cements in Recent reefs of the Barbados and Bahamas: keys to the past? *Ann. Soc. Géol. Belg.* 97: 153—158.

Schroeder J. H., Zankl H., 1974. Dynamic reef formation: a sedimentological concept based on studies of Recent Bermuda and Bahama reefs. IN: A. M. Cameron et al. (eds.), *Proc. 2nd Int. Symp. on Coral Reefs*, vol. 2, Great Barrier Reef Committee, Brisbane, p. 413—428.

Schwarz H. U., 1975. Sedimentary structures and facies analysis of shallow marine carbonates (Lower Muschelkalk, Middle Triassic, southwestern Germany). *Contributions to Sedimentology*, 3: 100 pp.

Senkowiczowa H., 1970. Trias. *Inst. Geol.*, Pr. 56: Stratygrafia mezozoiku obrzeżenia Gór Świętokrzyskich. Warszawa, p. 1—42.

Shinn E. A., 1969. Submarine lithification of Holocene carbonate sediments in the Persian Gulf. *Sedimentology*, 12: 109—144.

Siedlecka A., 1972. Lenght-slow chalcedony and relics of sulphates — evidence of evaporitic environments in the Upper Carboniferous and Permian beds of Bear Island, Svalbard. *J. Sedim. Petrol.*, 42: 812—816.

Skupin K., 1970. Feinstratigraphische und mikrofazielle Untersuchungen im Unteren Hauptmuschelkalk (Trochitenkalk) des Neckar — Jagst — Kocher — Gebietes. *Arb. Geol. Paläont. Inst. Univ. Stuttgart*, N. F. 63, 173 pp., Stuttgart.

Skupin K., 1973. Stratigraphy and microfacies in the crinoidal limestones (Trochiten limestone, Triassic) of southwest Germany. *Sediment. Geology*, 9: 1—19.

Stockman K. W., Ginsburg R. N., Shinn E. A., 1967. The production of lime mud by algae in south Florida. *J. Sediment. Petrol.*, 37: 633—648.

Strakhov N. M. — Страхов Н. М., 1953. Диагенез осадков и его значение для осадочного рудообразования *Изв. АН. СССР, сер. геол.*, 5: 12—49.

Strakhov N. M. — Страхов Н. М., 1960. Основы теории литогенеза. Т. I. Изд. АН СССР. Москва. стр. 210.

Wells A. J., Illing L. V., 1964. Present-day precipitation of calcium carbonate in the Persian Gulf. IN: L. M. J. U. Van Straaten (ed.), Deltaic and shallow marine deposits. *Development in sedimentology*, 1: 429—435. Elsevier, Amsterdam.

Winland H. D., 1968. The role of high-Mg calcite in the preservation of micrite envelopes and textural features of aragonite sediments. *J. Sediment. Petrol.*, 38: 1320—1325.

Wolf K. H., 1965. "Grain diminution" of algal colonies to micrite. *J. Sediment. Petrol.*, 35: 420—427.

Zankl H., 1969. Structural and textural evidence of early lithification in fine-grained carbonate rocks. *Sedimentology*, 12: 241—256.

Zankl H., 1971. A model of sedimentation and diagenesis in Triassic reef. IN: O. P. Bricker (ed.), *Carbonate cements*. Johns Hopkins Press, Baltimore, p. 189—192.

STRESZCZENIE

Praca jest poświęcona charakterystyce ortochemicznych składników skał węglanowych (mikryt, mikrospar, cement), ich związkowi z procesami diagenezy oraz przebiegowi diagenezy.

Składniki ortochemiczne

Wśród składników ortochemicznych mikryt ma najmniejsze znaczenie. Buduje on powłoki na elementach ziarnowych, niektóre peloidy, a czasem wypełnia wnętrza komór ślimaków.

Głównym składnikiem tła skalnego mikrosparytów, biomikrosparytów i biopelmikrosparytów jest mikrospar — diagenetyczny odpowiednik pierwotnego mułu węglanowego (Pl. I, fig. 1, 2). Muł węglanowy przypuszczalnie zawdzięcza swe pochodzenie mechanicznemu i biologicznemu kruszeniu elementów szkieletowych; część mułu może być wynikiem fizyko-chemicznego lub biochemicznego wytrącania $CaCO_3$ z wody morskiej. Muł węglanowy ulegał transportowi i mechanicznemu sortowaniu, tworząc osady poziomo i przekątnie warstwowane. Jego przekształcanie w mikrospar nastąpiło przypuszczalnie w drodze syntaksjalnej cementacji poszczególnych cząstek.

Cement węglanowy stanowi, obok elementów ziarnowych, główny składnik biosparytów i biopelsparytów, pojawia się również w innych rodzajach skał. Składają się nań dwie generacje: starsza, I generacja jest wykształcona w postaci bezżelazistego kalcytu stromościennego (Pl. II, fig. 3, Pl. IV, fig. 1), niekiedy o rozmiarach mikrosparu (Pl. I, fig. 1, 2, Pl. II, fig. 1). Młodsza, II generacja jest kalcytem żelazistym o zmiennej zawartości jonów Fe^{2+} i odznacza się blokowym wykształceniem (Pl. II, fig. 3, Pl. IV, fig. 1).

Przebieg diagenezy

Właściwa faza wczesnej diagenezy (stadium eogenetyczne) rozpoczęła się z chwilą końcowej depozycji osadu. Polegała ona na stopniowym odwadnianiu sedymentów, spadku porowatości, rozpuszczaniu organicznego aragonitu i wczesnej cementacji.

Cement I generacji tworzył się głównie w warunkach utleniających. Jego źródłem była przesycona węglanem wapnia woda morska przenikająca osad oraz ulegający rozpuszczeniu organiczny aragonit. Minerałem krystalizującym w postaci cementu I generacji był kalcyt, zawierający przypuszczalnie niewielkie domieszki $MgCO_3$. W wyższych ogniwach dolnego wapienia muszlowego (wyższa część warstw z Lima striata) można spodziewać się wzrostu zawartości Mg w cemencie kalcytowym w związku ze wzrostem zasolenia oraz usuwaniem z roztworów jonów Ca w postaci kalcytu i gipsu. Dla morza wapienia muszlowego sugeruje się odmienny od współczesnego stosunek Mg/Ca, przypuszczal-

nie niższy od 2:1, co pozwalało na krystalizację nieorganicznego kalcytu w postaci cementu I generacji.

Palisadowy cement kalcytowy o wielkości mikrosparu (Pl. I, fig. 1, 2) znaleziono na powierzchniach elementów rozsianych w mule węglanowym (w mikrosparytach i biomikrosparytach). Cementacja tych utworów przebiegała przypuszczalnie szybko, gdyż masowo niekiedy występujące koprolity nader rzadko wykazują ślady deformacji pod wpływem kompakcji. Zawaliskowe struktury kompakcyjne tworzyły się prawie wyłącznie wtedy, gdy niektóre aragonitowe elementy szkieletowe ulegając rozpuszczeniu we wczesnym stadium diagenezy, pozostawiły po sobie próżnie otulone cienkimi powłokami mikrytowymi lub w przypadku ślimaków, których komory mieszkalne były co najwyżej w nikłym stopniu wypełnione mułem.

Struktury zawaliskowe powstały po wykrystalizowaniu cementu I generacji, należy je więc wiązać z mezogenetycznym stadium diagenezy. W etapie tym, w związku ze wzrostem miąższości nadkładu i odcięciem dopływu świeżej wody morskiej, zanikł bezpośredni wpływ czynników powierzchniowych (podmorskich) na przebieg diagenezy.

Wskutek regresji morza w kajprze, przypuszczalnie pośredni wpływ na przebieg diagenezy wywarły wody meteoryczne, wsiąkające w głąb skał i mieszające się z reliktowymi wodami porowymi. Z roztworów tych rozpoczęła się krystalizacja cementu II generacji. Źródło węglanu wapnia nie jest bliżej znane. Przypuszczalnie część $CaCO_3$ pochodziła z zachowanych dotąd i rozpuszczanych aragonitowych elementów szkieletowych, część zaś z procesów rozpuszczania pod ciśnieniem (mikro- i makrostylolity).

Cement II generacji wytrącał się w postaci kalcytu blokowego w warunkach redukcyjnych, na co wskazuje obecność jonów Fe^{2+} w jego sieci przestrzennej.

Równocześnie z krystalizacją cementu blokowego rozpoczęły się procesy neomorfizmu (rekrystalizacji), ograniczone głównie do niektórych elementów szkieletowych, zbudowanych prawdopodobnie z Mg-kalcytu. W wyniku przemian neomorficznych pierwotna struktura tych szczątków uległa w znacznej mierze zatarciu (Pl. IV, fig. 2, 3, 4, 5).

Stadium telogenetyczne rozpoczęło się z chwilą dźwignięcia skał do strefy powierzchniowej. Do procesów związanych z tym etapem należy rozwój zjawisk krasowych, rozpuszczanie gipsu oraz częściowe uruchamianie i wytrącanie krzemionki.

EXPLANATION OF PLATES — OBJAŚNIENIA PLANSZ

Plate — Plansza I

Fig. 1. Skeletal fragment with microsparite cement crust, matrix built of microspar, biomicrosparite. Lower Muschelkalk, Wellenkalk, Wolica. Leached thin section, SEM.

Fig. 1. Element szkieletowy obrośnięty mikrosparytowym cementem, tło skalne zbudowane z mikrosparu, biomikrosparyt. Dolny wapień muszlowy, warstwy faliste, Wolica. Wytrawiona płytka cienka, mikrofotografia skaningowa.

Fig. 2. Skeletal fragment with microsparite cement crust, matrix built of microspar, biomicrosparite. Lower Muschelkalk, Wellenkalk, Wolica. Leached thin section, SEM.

Fig. 2. Element szkieletowy z narastającym cementem mikrosparytowym, tło skalne zbudowane z mikrosparu, biomikrosparyt. Dolny wapień muszlowy, warstwy faliste, Wolica. Wytrawiona płytka cienka, mikrofotografia skaningowa.

Plate — Plansza II

Fig. 1. Skeletal fragment with microsparite cement crust, matrix built of microspar, biomicrosparite. Lower Muschelkalk, Wellenkalk, Radkowice. Thin section, SEM.

Fig. 1. Element szkieletowy z narastającym cementem mikrosparytowym, tło skalne zbudowane z mikrosparu, biomikrosparyt. Dolny wapień muszlowy, warstwy faliste, Radkowice. Płytka cienka, mikrofotografia skaningowa.

Fig. 2. Fragment of micrite envelope (M) covered with cement of the first generation (CI), cast is built of the second generation cement (CII), biosparite. Lower Muschelkalk, Wolica Beds, Wolica. Thin section, SEM.

Fig. 2. Fragment powłoki mikrytowej (M) z narastającym cementem I generacji (CI), odlew zbudowany z cementu II generacji (CII), biosparyt. Dolny wapień muszlowy, warstwy wolickie, Wolica. Płytka cienka, mikrofotografia skaningowa.

Fig. 3. Fragment of an ostracod shell with cement of the first generation developed on both the external and internal sides. The inside (left side, bottom) filled with cement of the second generation, in the right upper corner matrix built of microspar, biomicrosparite. Lower Muschelkalk, Wellenkalk, Wolica. Thin section, SEM.

Fig. 3. Fragment ściany pancerzyka małżoraczka z cementem I generacji rozwiniętym na zewnętrznej i wewnętrznej powierzchni. Wnętrze (lewa strona, dół) wypełnione cementem II generacji, w prawym górnym narożu mikrospar tła skalnego, biomikrosparyt. Dolny wapień muszlowy, warstwy faliste, Wolica. Płytka cienka, mikrofotografia skaningowa.

Fig. 4. Fragment of pelecypod prismatic structure, in the left upper corner a cavity formed by micro-borers, filled with micrite, biosparite. Lower Muschelkalk, Wolica Beds, Brzeziny. Thin section, SEM.

Fig. 4. Fragment pryzmatycznej struktury małża, w lewym górnym narożu wydrążenie utworzone przez mikroskałotocze, wypełnione mikrytem, biosparyt. Dolny wapień muszlowy, warstwy wolickie, Brzeziny. Płytka cienka, mikrofotografia skaningowa.
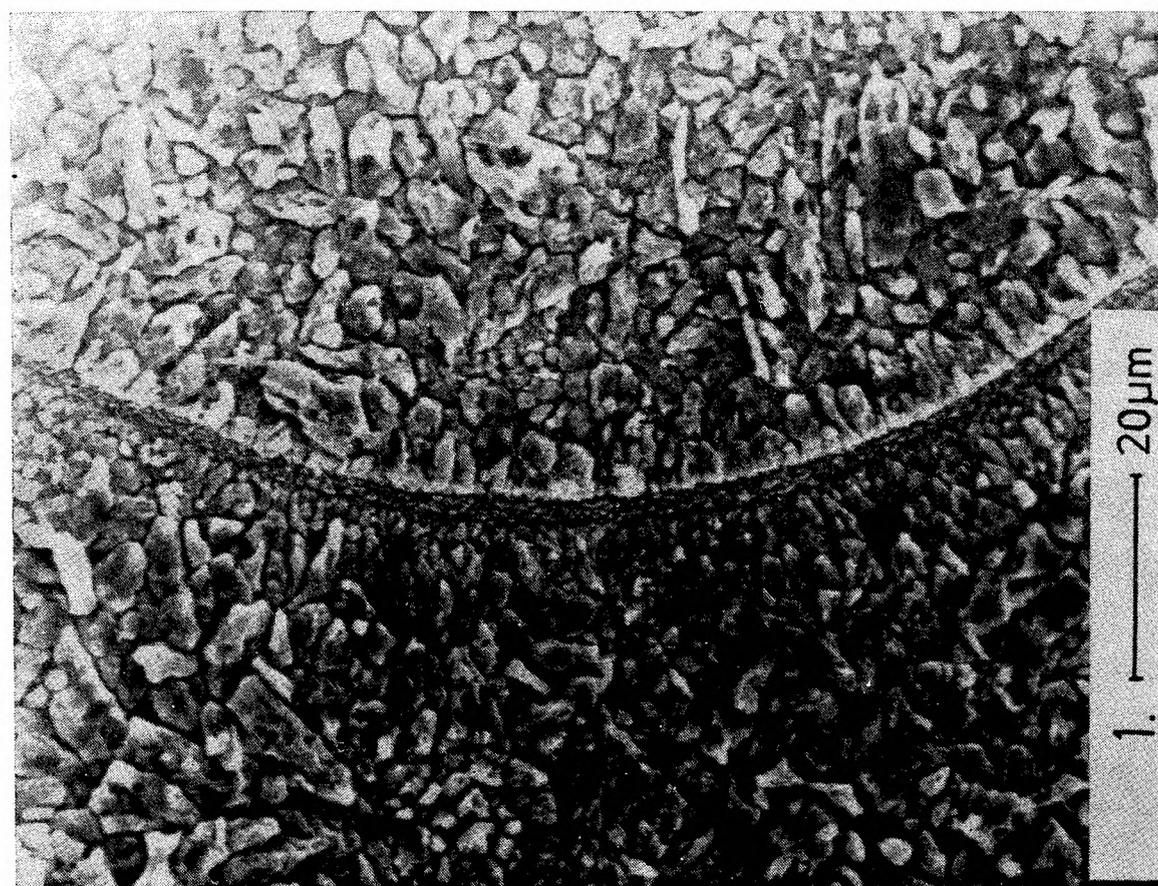
Plate — Plansza III

Fig. 1. Microsparite horizontally laminated, laminae graded bedded. Permian, Bolechowice. Thin section, negative print.

Fig. 1. Mikrosparyt laminowany poziomo, laminy uziarnione frakcjonalnie. Perm, Bolechowice. Płytka cienka, odbitka negatywowa.

Fig. 2. Fragment of pelecypod shell with locally preserved primary structure (arrow), in places neomorphic calcite (N) with traces of growth lines, biomi-
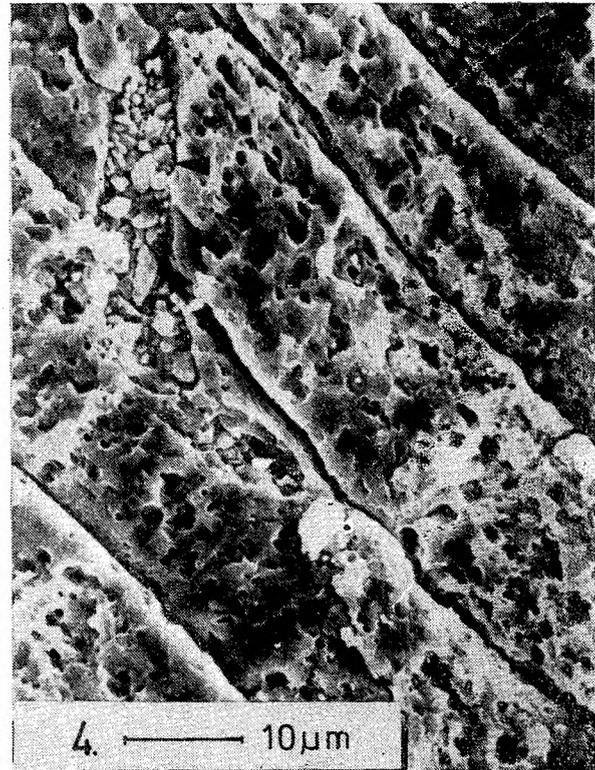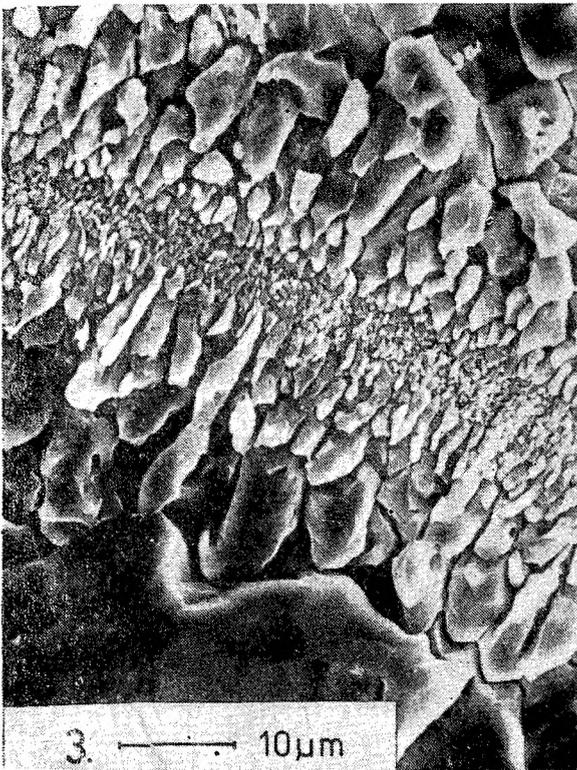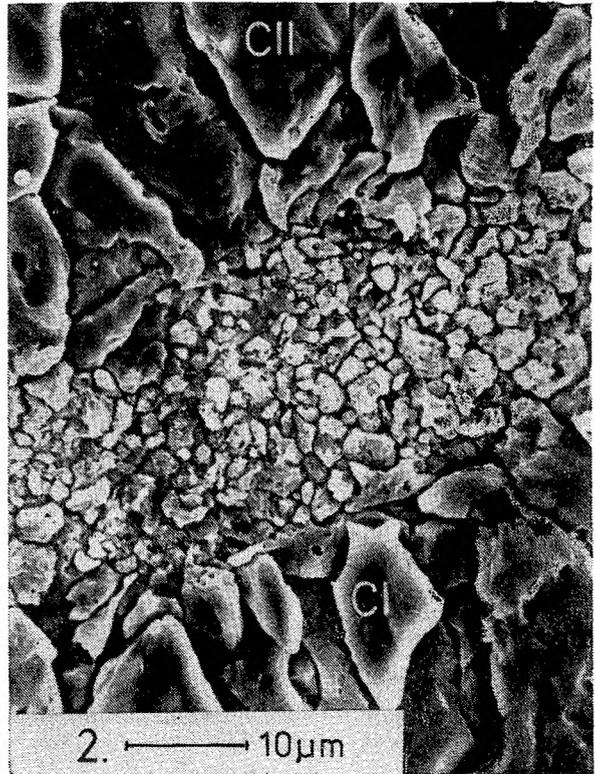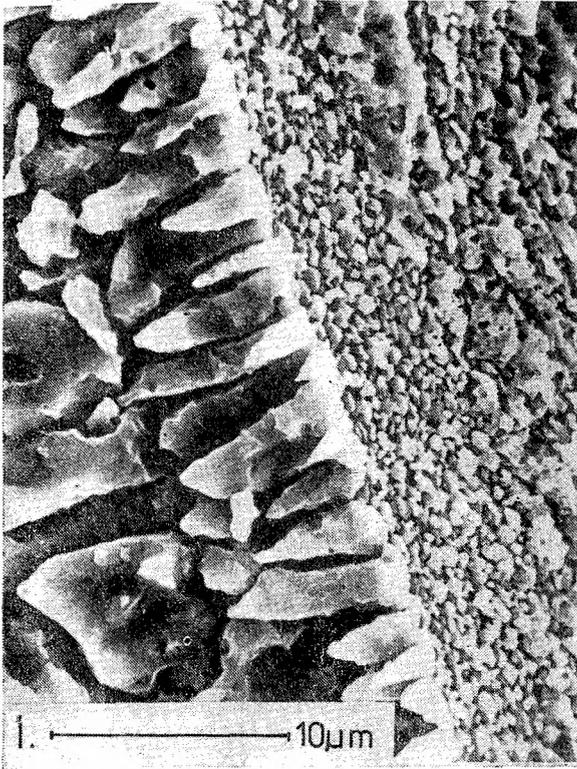
crosparite. Lower Muschelkalk, Lima striata Beds, Wolica. Thin section, one nicol.

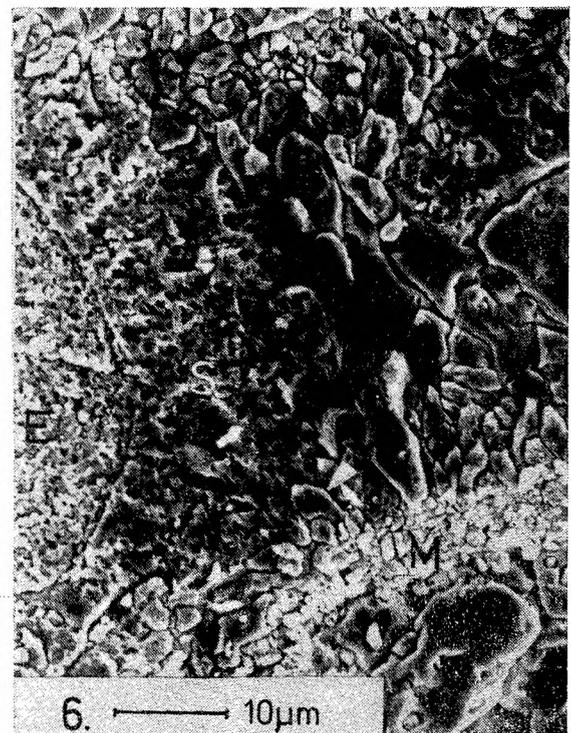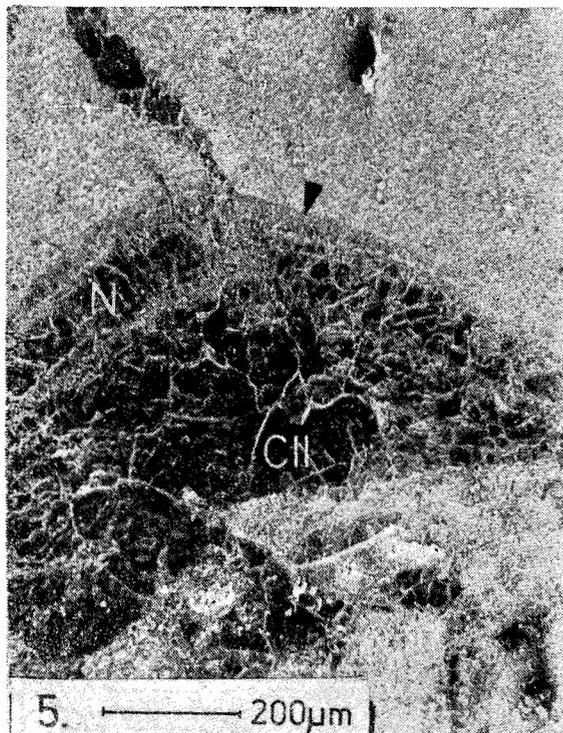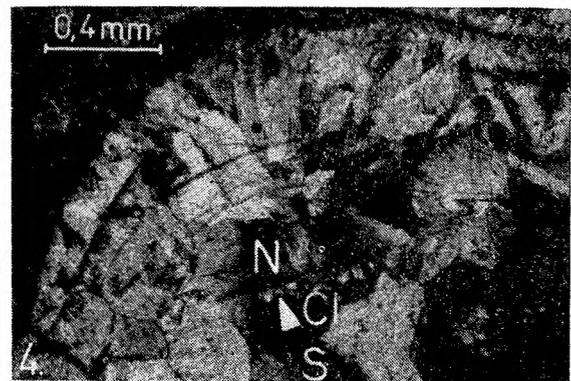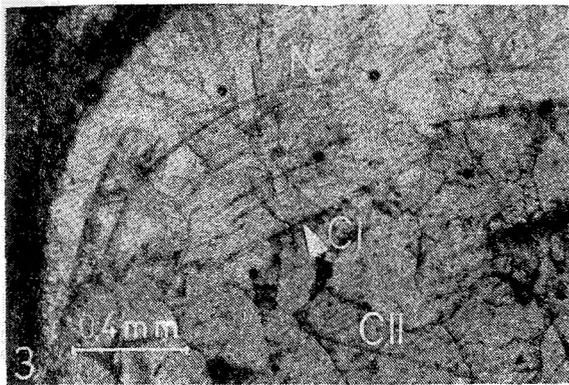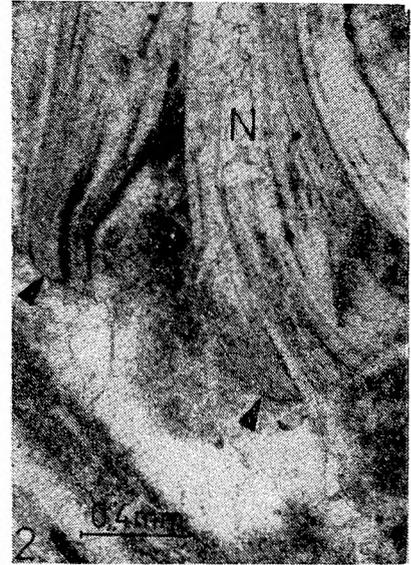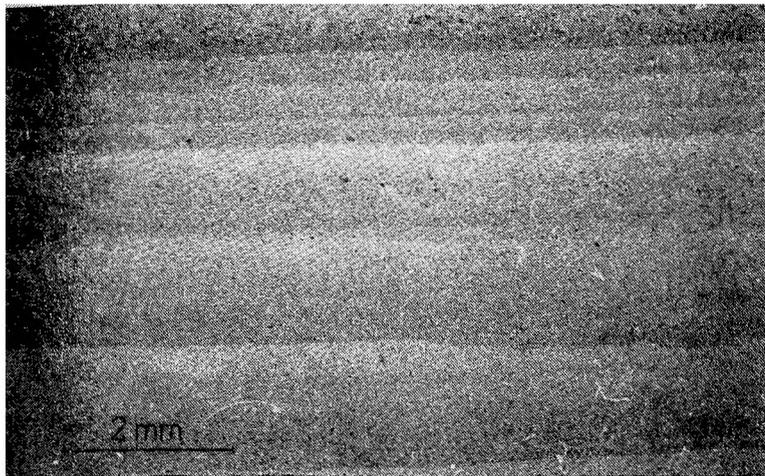Fig. 2. Fragment skorupy małża z lokalnie zachowaną pierwotną strukturą (strzałka), miejscami kalcyt neomorficzny (N) ze śladami linii przyrostowych, biomikrosparyt. Dolny wapień muszlowy, warstwy z Lima striata, Wolica. Płytka cienka, 1 nikol.

Fig. 3. Another fragment of the same shell: fading out traces of growth lines in neomorphic calcite (N) mosaic. Poorly formed cement of the first generation (CI, arrow), well formed cement of the second generation (CII). Thin section, one nicol.

Fig. 3. Inny fragment tej samej skorupy: na tle neomorficznego kalcytu (N) zanikające ślady linii przyrostowych. Słabo wykształcony cement I generacji (CI, strzałka), dobrze wykształcony cement II generacji (CII). Płytka cienka, 1 nikol.

Fig. 4. As above, nicols crossed. Visible cement of the first generation (arrow). Cement of the second generation is in optical continuity (S) with neomorphic calcite (N).

Fig. 4. Jak wyżej, nikole skrzyżowane. Widoczny cement I generacji (strzałka). Cement II generacji narasta w ciągłości optycznej (S) z neomorficznym kalcytem (N).

Fig. 5. The same shell. Visible fragments of preserved structure (arrow), neomorphic calcite (N) and cement of the second generation. Thin section, SEM.

Fig. 5. Ta sama skorupa. Widoczne fragmenty z zachowaną strukturą pierwotną (strzałka), neomorficzny kalcyt (N) oraz cement II generacji. Płytka cienka, mikrofotografia skaningowa.

Fig. 6. Echinoderm fragment (E) with syntaxial cement (S) and fragment of micrite envelope (M) with initial cement of the first generation, development of which was hamper by the faster growing syntaxial cement (arrow), biosparite. Lower Muschelkalk, Wolica Beds, Wolica. Thin section, SEM.

Fig. 6. Fragment szkarłupnia (E) z syntaksjalnym cementem (S) oraz fragment powłoki mikrytowej (M) z inicjalnym cementem I generacji, którego rozwój uległ zahamowaniu wskutek szybszego wzrostu cementu syntaksjalnego (strzałka), biosparyt. Dolny wapień muszlowy, warstwy wolickie, Wolica. Płytka cienka, mikrofotografia skaningowa.
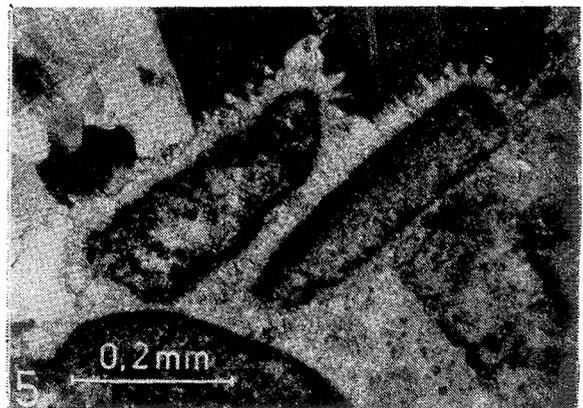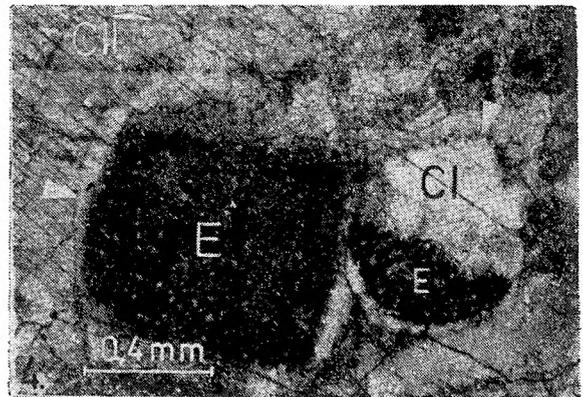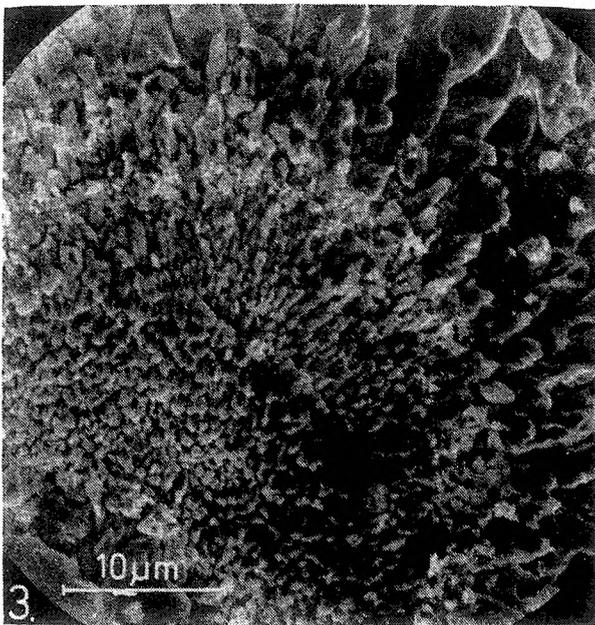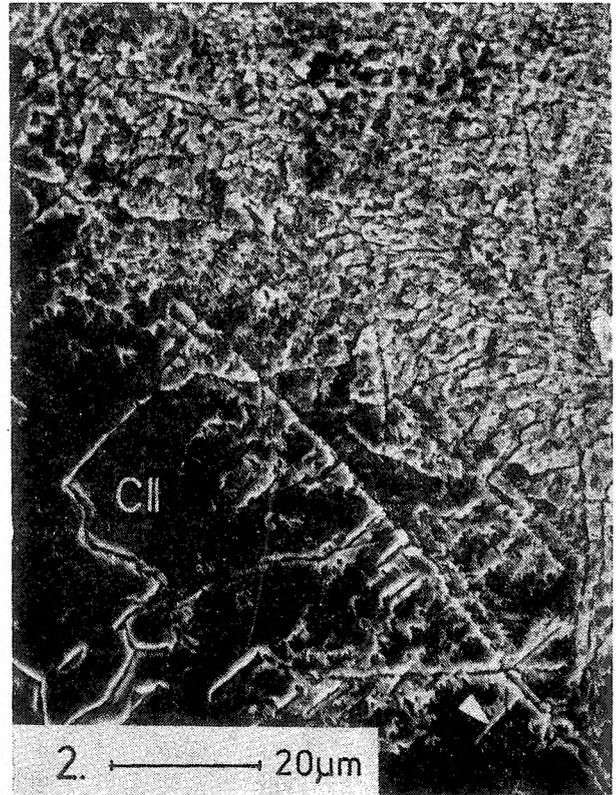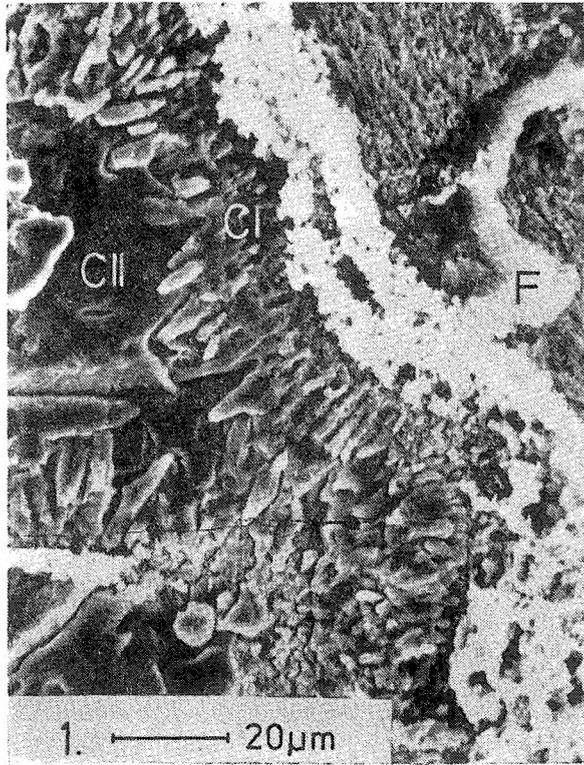
Plate — Plansza IV

Fig. 1. Steep-faced palisade cement of the first generation (CI) developed on skeletal fragments impregnated with iron hydroxide (F). In pore spaces blocky cement of the second generation (CII), biosparite. Lower Muschelkalk, Lima striata Beds, Wolica. Thin section, SEM.

Fig. 1. Stromościenny cement palisadowy I generacji (CI) rozwinięty na elementach szkieletowych przepojonych wodorotlenkami żelaza (F). W porach cement blokowy II generacji (CII), biosparyt. Dolny wapień muszlowy, warstwy z Lima striata, Wolica. Płytka cienka, mikrofotografia skaningowa.

Fig. 2. Microstructure of calcite layer of a Lima shell (L) with blocky cement of the second generation (CII). In the cement crystals close to the calcite shell layer, pores are visible, probably relics after aragonite cement of the first (?) generation (arrow). Lower Muschelkalk, Lima striata Beds, Piekoszów IG—1. Thin section, SEM.

Fig. 2. Mikrostruktura kalcytowej warstwy skorupy Limy (L) z narastającym cementem blokowym II generacji (CII). W kryształach cementu przyrastających bezpośrednio do kalcytowej skorupy widoczne drobne pory, być może, relikty po aragonitowym cemencie I (?) generacji (strzałka). Dolny wapień

1. |———————— 10μm

2. |———————— 10μm

3. |————— 10μm

4. |————— 10μm

Pl. III

A. Kostecka

1. ⊢————⊣ 20μm

2. ⊢————⊣ 20μm

3. 10μm

0.4 mm

5. ⊢————⊣ 0.2 mm

muszlowy, warstwy z Lima striata, Piekoszów IG—1. Płytka cienka, mikrofotografia skaningowa.

Fig. 3. Fragment of nodosariid test of radial microstructure with syntaxially growing cement of the first generation. Lower Muschelkalk, Łukowa Beds, Wolica. Thin section, SEM.

Fig. 3. Fragment pancerzyka nodosarii o radialnej mikrostrukturze z narastającym syntaksjalnie cementem I generacji. Dolny wapień muszlowy, warstwy łukowskie, Wolica. Płytka cienka, mikrofotografia skaningowa.

Fig. 4. Crinoid fragments as bioclastic nuclei (E) for the syntaxially growing cement of the first (CI) and the second (CII) generations. At the contact of these cements dark rim (arrow). Lower Muschelkalk, Wellenkalk, Piekoszów IG—1. Thin section stained with the alizarine red and potassium ferrycyanide, one nicol.

Fig. 4. Fragmenty liliowców jako bioklastyczne jądra (E) dla syntaksjalnie narastającego cementu I (CI) i II generacji (CII). Na kontakcie cementu I i II generacji ciemna obwódka (strzałka). Dolny wapień muszlowy, warstwy faliste, Piekoszów IG—1. Płytka cienka barwiona czerwienią alizarinową i żelazicyankiem potasu, 1 nikol.

Fig. 5. Steep-faced palisade cement of the first generation on grain surfaces. Pore spaces filled with blocky cement of the second generation, biopelsparite. Lower Muschelkalk, Lima striata Beds, Wolica. Thin section, crossed nicols.

Fig. 5. Stromościenny cement palisadowy I generacji narastający na elementach ziarnowych. Pory wypełnione cementem blokowym II generacji, biopelsparyt. Dolny wapień muszlowy, warstwy z Lima striata, Wolica. Płytka cienka, nikole skrzyżowane.